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Naganuma

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(54) CONFIDENTIAL COMPUTATION SYSTEM, CONFIDENTIAL COMPUTATION METHOD, AND CONFIDENTIAL COMPUTATION PROGRAM

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H04L 9/00 (2006.01)
H04L 9/30 (2006.01)

(52) **U.S. Cl.**
CPC ***H04L 9/008*** (2013.01); ***H04L 9/3093*** (2013.01); *G06F 21/60* (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

(56) **References Cited**

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* cited by examiner

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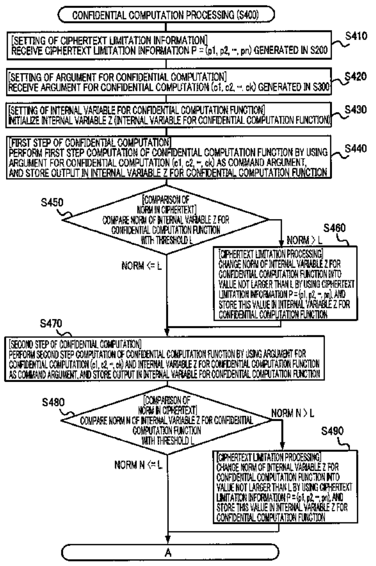
(57) ABSTRACT

A client executes processing for data encryption by adding an error vector to plaintext, the error vector being not larger than a predetermined criterion and processing for sending limitation information to a server, the limitation information being formed from a sublattice basis of a lattice generated by a secret key. The server executes processing for receiving the limitation information and storing it in a storage device and in the homomorphic computation processing on the encrypted data received from the client, processing for, when a bit length of ciphertext which is a result of the homomorphic computation processing is equal to or larger than a predetermined value, reducing the bit length of the ciphertext to a value not larger than a predetermined threshold by translating a vector of the ciphertext to an inside of a region formed from the sublattice basis corresponding to the stored limitation information.

5 Claims, 11 Drawing Sheets


CONFIDENTIAL COMPUTATION PROCESSING (S400)
[SETTING OF CIPHERTEXT LIMITATION INFORMATION] RECEIVE CIPHERTEXT LIMITATION INFORMATION P = (p1, p2, ···, pn) GENERATED IN S200
S410
[SETTING OF ARGUMENT FOR CONFIDENTIAL COMPUTATION] RECEIVE ARGUMENT FOR CONFIDENTIAL COMPUTATION (c1, c2, ···, ck) GENERATED IN S300
S420
[SETTING OF INTERNAL VARIABLE FOR CONFIDENTIAL COMPUTATION FUNCTION] INITIALIZE INTERNAL VARIABLE Z (INTERNAL VARIABLE FOR CONFIDENTIAL COMPUTATION FUNCTION)
S430
[FIRST STEP OF CONFIDENTIAL COMPUTATION] PERFORM FIRST STEP COMPUTATION OF CONFIDENTIAL COMPUTATION FUNCTION BY USING ARGUMENT FOR CONFIDENTIAL COMPUTATION (c1, c2, ···, ck) AS COMMAND ARGUMENT, AND STORE OUTPUT IN INTERNAL VARIABLE Z FOR CONFIDENTIAL COMPUTATION FUNCTION
S440
S450
[COMPARISON OF NORM IN CIPHERTEXT] COMPARE NORM OF INTERNAL VARIABLE Z FOR CONFIDENTIAL COMPUTATION FUNCTION WITH THRESHOLD L
NORM > L
S460
[CIPHERTEXT LIMITATION PROCESSING] CHANGE NORM OF INTERNAL VARIABLE Z FOR CONFIDENTIAL COMPUTATION FUNCTION INTO VALUE NOT LARGER THAN L BY USING CIPHERTEXT LIMITATION INFORMATION P = (p1, p2, ···, pn), AND STORE THIS VALUE IN INTERNAL VARIABLE Z FOR CONFIDENTIAL COMPUTATION FUNCTION
NORM <= L
S470
[SECOND STEP OF CONFIDENTIAL COMPUTATION] PERFORM SECOND STEP COMPUTATION OF CONFIDENTIAL COMPUTATION FUNCTION BY USING ARGUMENT FOR CONFIDENTIAL COMPUTATION (c1, c2, ···, ck) AND INTERNAL VARIABLE Z FOR CONFIDENTIAL COMPUTATION FUNCTION AS COMMAND ARGUMENT, AND STORE OUTPUT IN INTERNAL VARIABLE FOR CONFIDENTIAL COMPUTATION FUNCTION
S480
[COMPARISON OF NORM IN CIPHERTEXT] COMPARE NORM N OF INTERNAL VARIABLE Z FOR CONFIDENTIAL COMPUTATION FUNCTION WITH THRESHOLD L
NORM N > L
S490
[CIPHERTEXT LIMITATION PROCESSING] CHANGE NORM OF INTERNAL VARIABLE Z FOR CONFIDENTIAL COMPUTATION FUNCTION INTO VALUE NOT LARGER THAN L BY USING CIPHERTEXT LIMITATION INFORMATION P = (p1, p2, ···, pn), AND STORE THIS VALUE IN INTERNAL VARIABLE Z FOR CONFIDENTIAL COMPUTATION FUNCTION
NORM N <= L
A

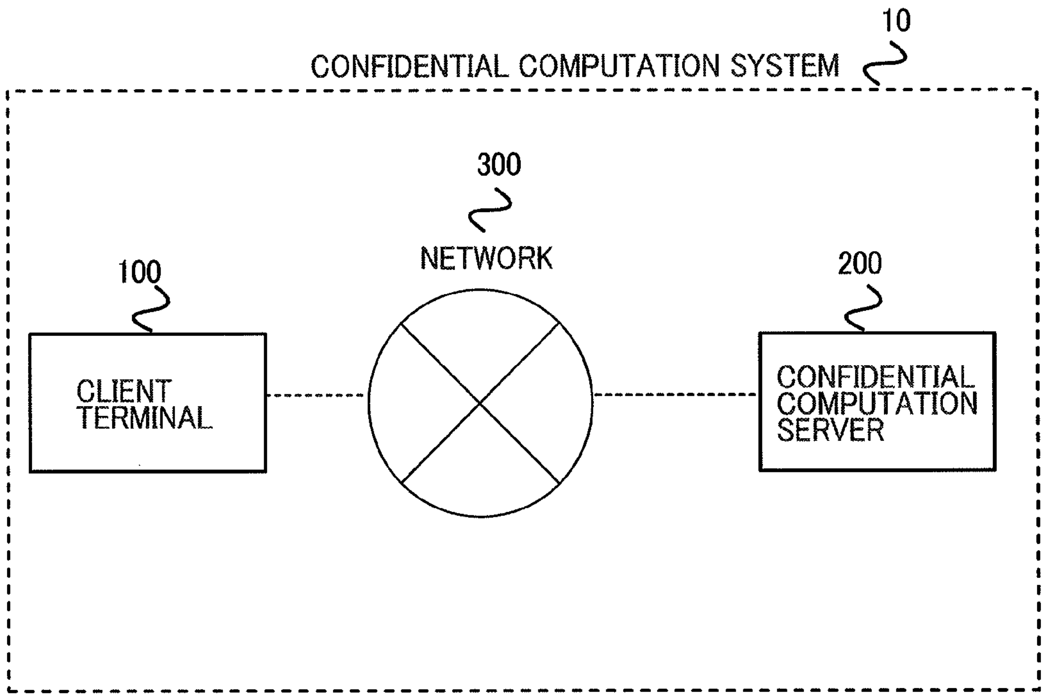

10
CONFIDENTIAL COMPUTATION SYSTEM
300
NETWORK
100
CLIENT TERMINAL
200
CONFIDENTIAL COMPUTATION SERVER

FIG. 1

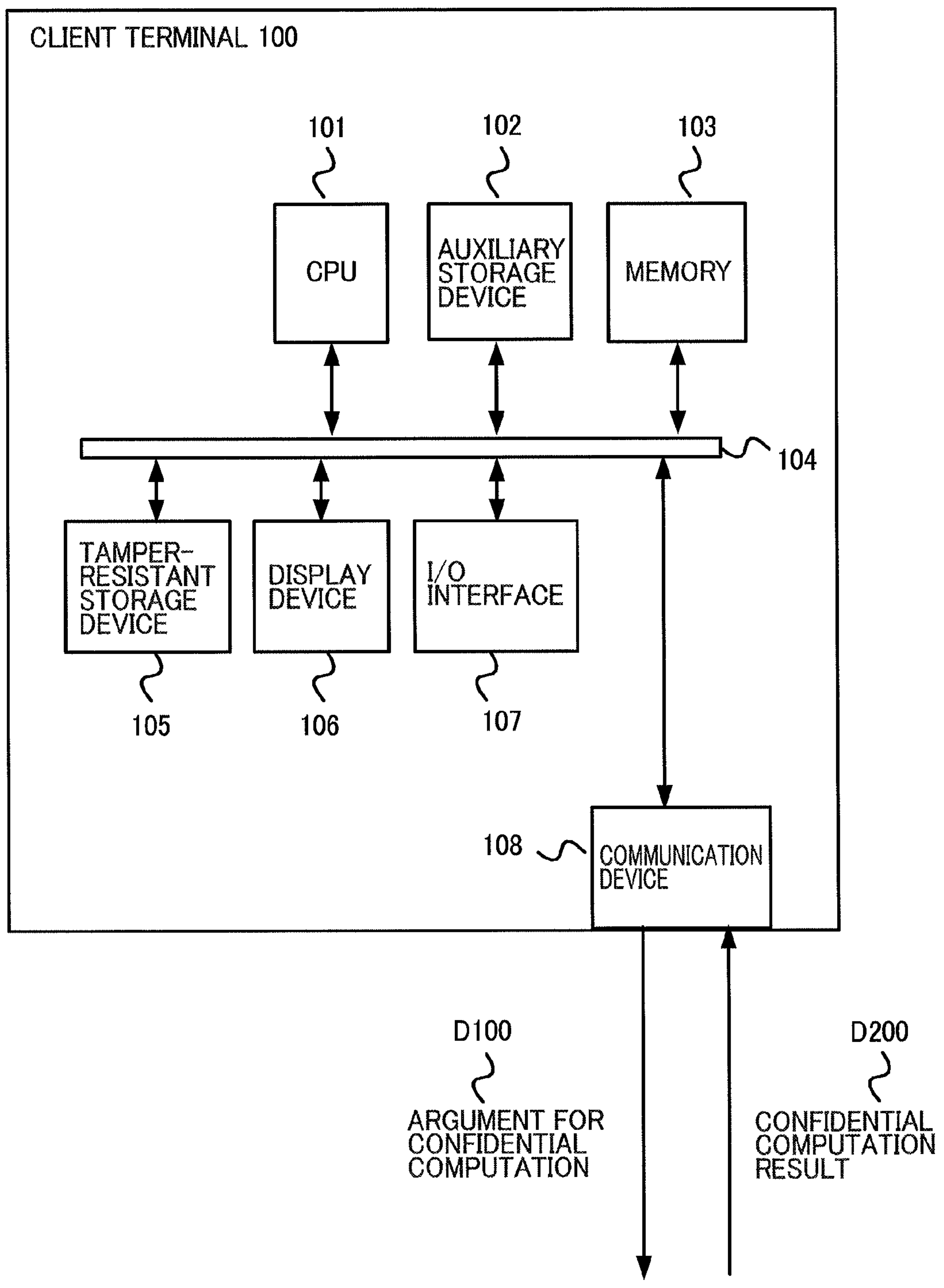

CLIENT TERMINAL 100
101
102
103
CPU
AUXILIARY STORAGE DEVICE
MEMORY
104
TAMPER-RESISTANT STORAGE DEVICE
DISPLAY DEVICE
I/O INTERFACE
105
106
107
108
COMMUNICATION DEVICE
D100
ARGUMENT FOR CONFIDENTIAL COMPUTATION
D200
CONFIDENTIAL COMPUTATION RESULT

FIG. 2

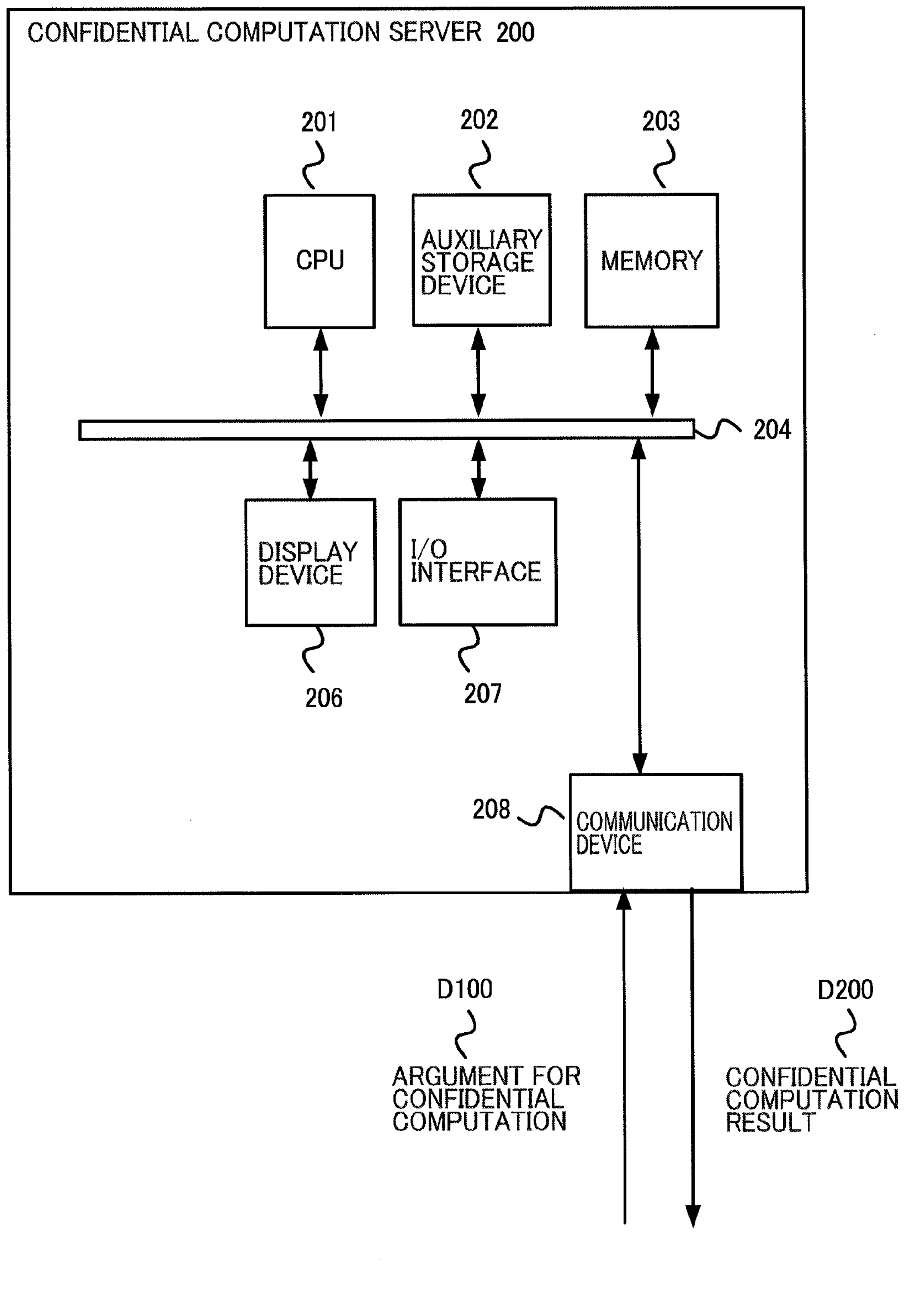

CONFIDENTIAL COMPUTATION SERVER 200
201
202
203
CPU
AUXILIARY STORAGE DEVICE
MEMORY
204
DISPLAY DEVICE
I/O INTERFACE
206
207
208
COMMUNICATION DEVICE
D100
ARGUMENT FOR CONFIDENTIAL COMPUTATION
D200
CONFIDENTIAL COMPUTATION RESULT

FIG. 3

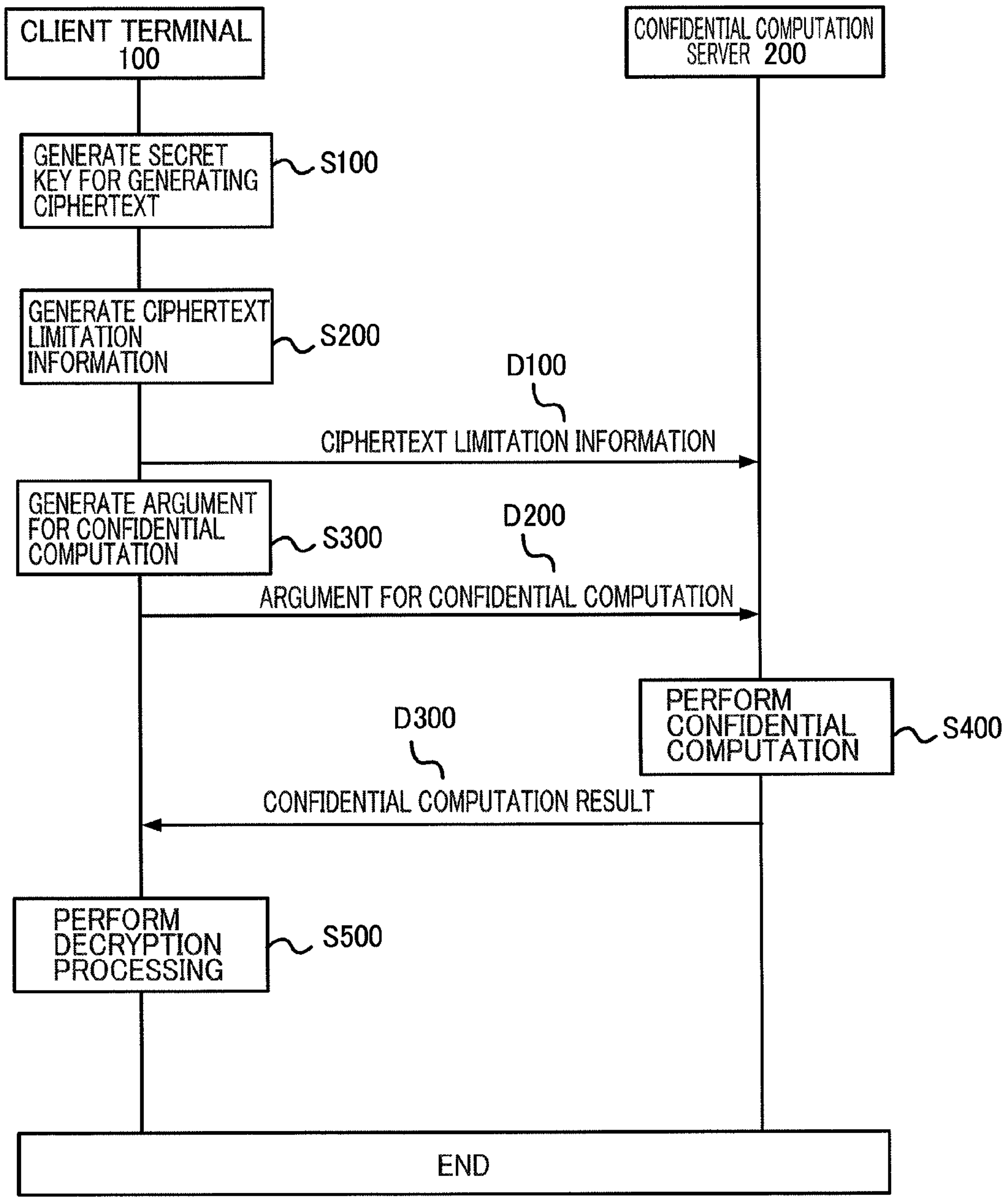

CLIENT TERMINAL 100
CONFIDENTIAL COMPUTATION SERVER 200
GENERATE SECRET KEY FOR GENERATING CIPHERTEXT
S100
GENERATE CIPHERTEXT LIMITATION INFORMATION
S200
D100
CIPHERTEXT LIMITATION INFORMATION
GENERATE ARGUMENT FOR CONFIDENTIAL COMPUTATION
S300
D200
ARGUMENT FOR CONFIDENTIAL COMPUTATION
PERFORM CONFIDENTIAL COMPUTATION
S400
D300
CONFIDENTIAL COMPUTATION RESULT
PERFORM DECRYPTION PROCESSING
S500
END

FIG. 4

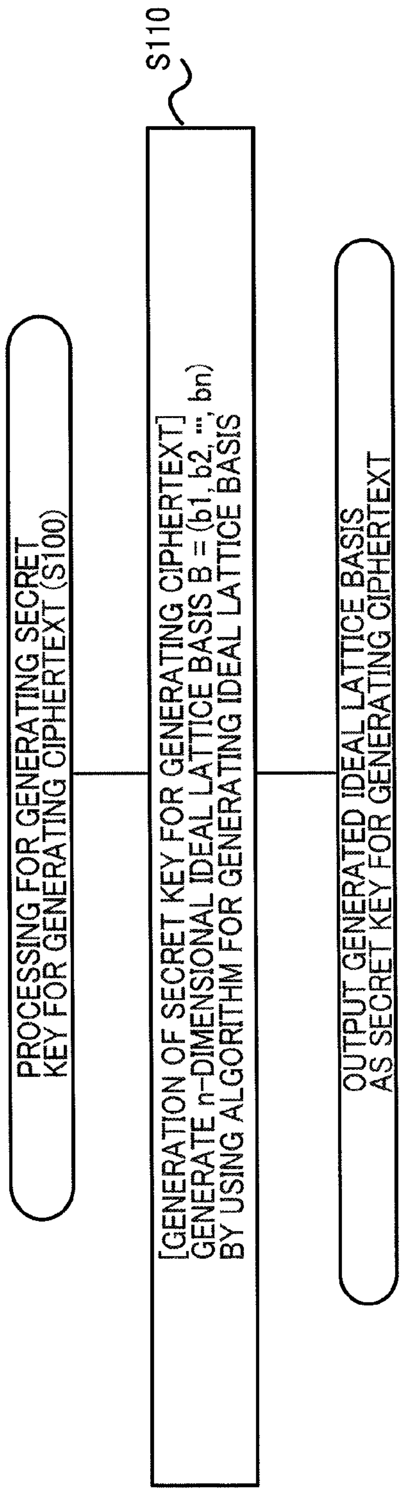

PROCESSING FOR GENERATING SECRET KEY FOR GENERATING CIPHERTEXT (S100)
S110
[GENERATION OF SECRET KEY FOR GENERATING CIPHERTEXT]
GENERATE n-DIMENSIONAL IDEAL LATTICE BASIS B = (b1, b2, ···, bn) BY USING ALGORITHM FOR GENERATING IDEAL LATTICE BASIS
OUTPUT GENERATED IDEAL LATTICE BASIS AS SECRET KEY FOR GENERATING CIPHERTEXT

FIG. 5

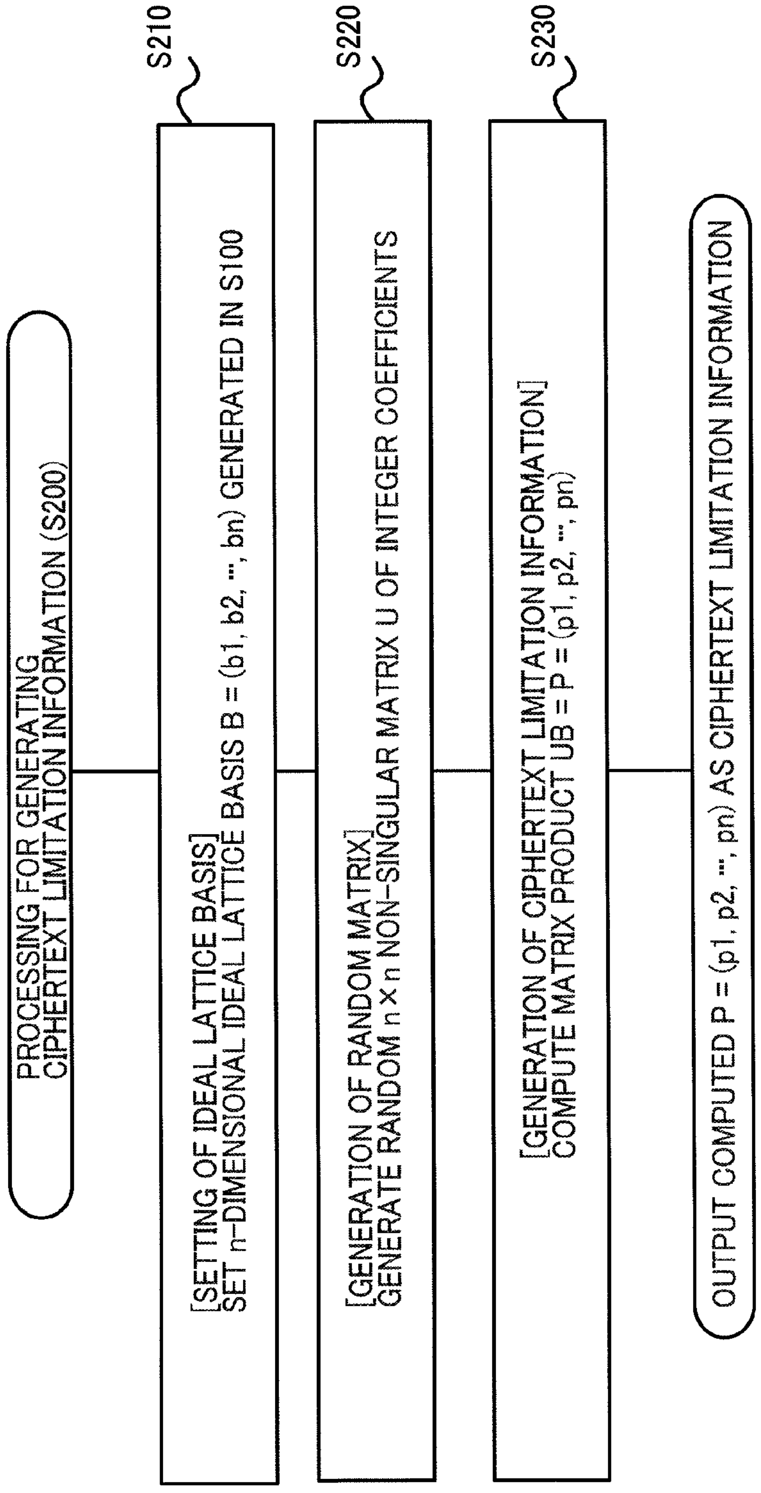

PROCESSING FOR GENERATING CIPHERTEXT LIMITATION INFORMATION (S200)
S210
[SETTING OF IDEAL LATTICE BASIS]
SET n-DIMENSIONAL IDEAL LATTICE BASIS B = (b1, b2, ···, bn) GENERATED IN S100
S220
[GENERATION OF RANDOM MATRIX]
GENERATE RANDOM n × n NON-SINGULAR MATRIX U OF INTEGER COEFFICIENTS
S230
[GENERATION OF CIPHERTEXT LIMITATION INFORMATION]
COMPUTE MATRIX PRODUCT UB = P = (p1, p2, ···, pn)
OUTPUT COMPUTED P = (p1, p2, ···, pn) AS CIPHERTEXT LIMITATION INFORMATION

FIG. 6

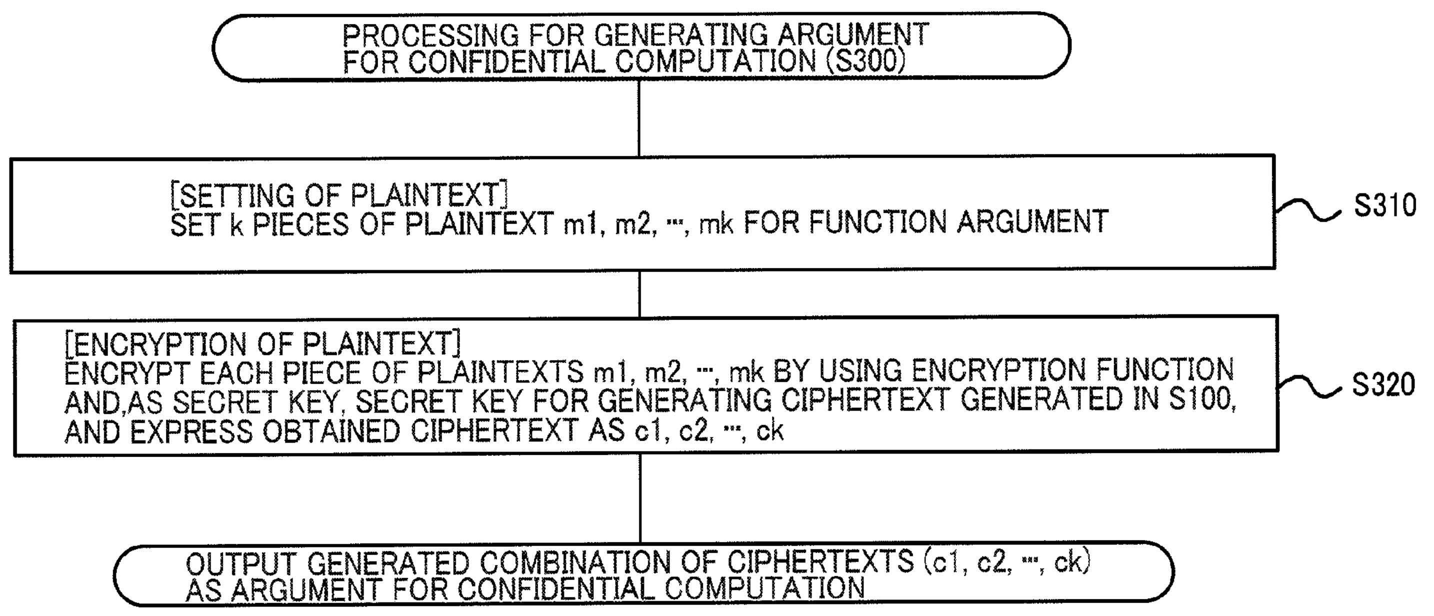

PROCESSING FOR GENERATING ARGUMENT FOR CONFIDENTIAL COMPUTATION (S300)
[SETTING OF PLAINTEXT] SET k PIECES OF PLAINTEXT m1, m2, ···, mk FOR FUNCTION ARGUMENT
S310
[ENCRYPTION OF PLAINTEXT] ENCRYPT EACH PIECE OF PLAINTEXTS m1, m2, ···, mk BY USING ENCRYPTION FUNCTION AND,AS SECRET KEY, SECRET KEY FOR GENERATING CIPHERTEXT GENERATED IN S100, AND EXPRESS OBTAINED CIPHERTEXT AS c1, c2, ···, ck
S320
OUTPUT GENERATED COMBINATION OF CIPHERTEXTS (c1, c2, ···, ck) AS ARGUMENT FOR CONFIDENTIAL COMPUTATION

FIG. 7

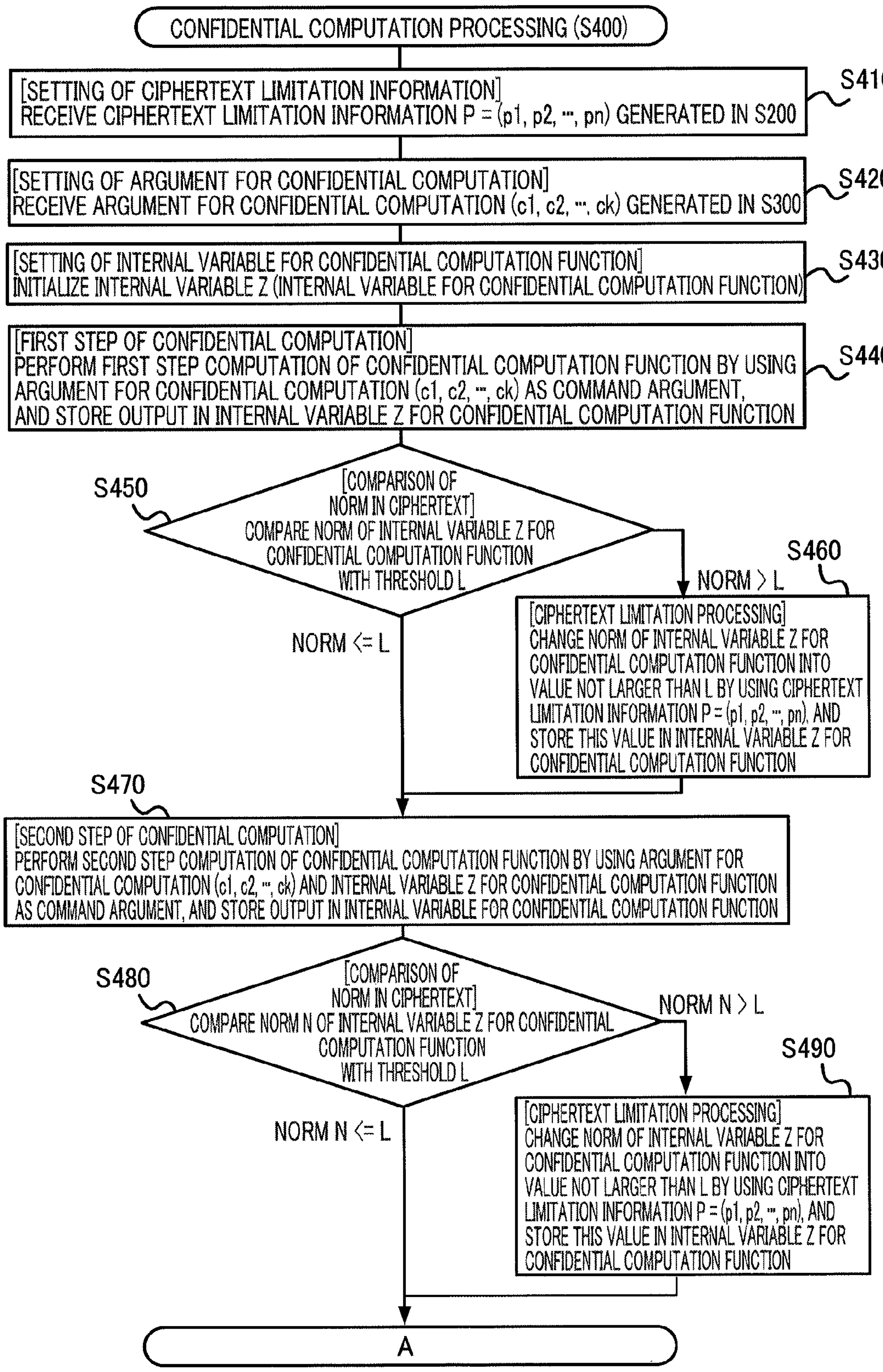

CONFIDENTIAL COMPUTATION PROCESSING (S400)
S410
[SETTING OF CIPHERTEXT LIMITATION INFORMATION]
RECEIVE CIPHERTEXT LIMITATION INFORMATION P = (p1, p2, ···, pn) GENERATED IN S200
S420
[SETTING OF ARGUMENT FOR CONFIDENTIAL COMPUTATION]
RECEIVE ARGUMENT FOR CONFIDENTIAL COMPUTATION (c1, c2, ···, ck) GENERATED IN S300
S430
[SETTING OF INTERNAL VARIABLE FOR CONFIDENTIAL COMPUTATION FUNCTION]
INITIALIZE INTERNAL VARIABLE Z (INTERNAL VARIABLE FOR CONFIDENTIAL COMPUTATION FUNCTION)
S440
[FIRST STEP OF CONFIDENTIAL COMPUTATION]
PERFORM FIRST STEP COMPUTATION OF CONFIDENTIAL COMPUTATION FUNCTION BY USING ARGUMENT FOR CONFIDENTIAL COMPUTATION (c1, c2, ···, ck) AS COMMAND ARGUMENT, AND STORE OUTPUT IN INTERNAL VARIABLE Z FOR CONFIDENTIAL COMPUTATION FUNCTION
S450
[COMPARISON OF NORM IN CIPHERTEXT]
COMPARE NORM OF INTERNAL VARIABLE Z FOR CONFIDENTIAL COMPUTATION FUNCTION WITH THRESHOLD L
NORM > L
NORM <= L
S460
[CIPHERTEXT LIMITATION PROCESSING]
CHANGE NORM OF INTERNAL VARIABLE Z FOR CONFIDENTIAL COMPUTATION FUNCTION INTO VALUE NOT LARGER THAN L BY USING CIPHERTEXT LIMITATION INFORMATION P = (p1, p2, ···, pn), AND STORE THIS VALUE IN INTERNAL VARIABLE Z FOR CONFIDENTIAL COMPUTATION FUNCTION
S470
[SECOND STEP OF CONFIDENTIAL COMPUTATION]
PERFORM SECOND STEP COMPUTATION OF CONFIDENTIAL COMPUTATION FUNCTION BY USING ARGUMENT FOR CONFIDENTIAL COMPUTATION (c1, c2, ···, ck) AND INTERNAL VARIABLE Z FOR CONFIDENTIAL COMPUTATION FUNCTION AS COMMAND ARGUMENT, AND STORE OUTPUT IN INTERNAL VARIABLE FOR CONFIDENTIAL COMPUTATION FUNCTION
S480
[COMPARISON OF NORM IN CIPHERTEXT]
COMPARE NORM N OF INTERNAL VARIABLE Z FOR CONFIDENTIAL COMPUTATION FUNCTION WITH THRESHOLD L
NORM N > L
NORM N <= L
S490
[CIPHERTEXT LIMITATION PROCESSING]
CHANGE NORM OF INTERNAL VARIABLE Z FOR CONFIDENTIAL COMPUTATION FUNCTION INTO VALUE NOT LARGER THAN L BY USING CIPHERTEXT LIMITATION INFORMATION P = (p1, p2, ···, pn), AND STORE THIS VALUE IN INTERNAL VARIABLE Z FOR CONFIDENTIAL COMPUTATION FUNCTION
A

FIG. 8

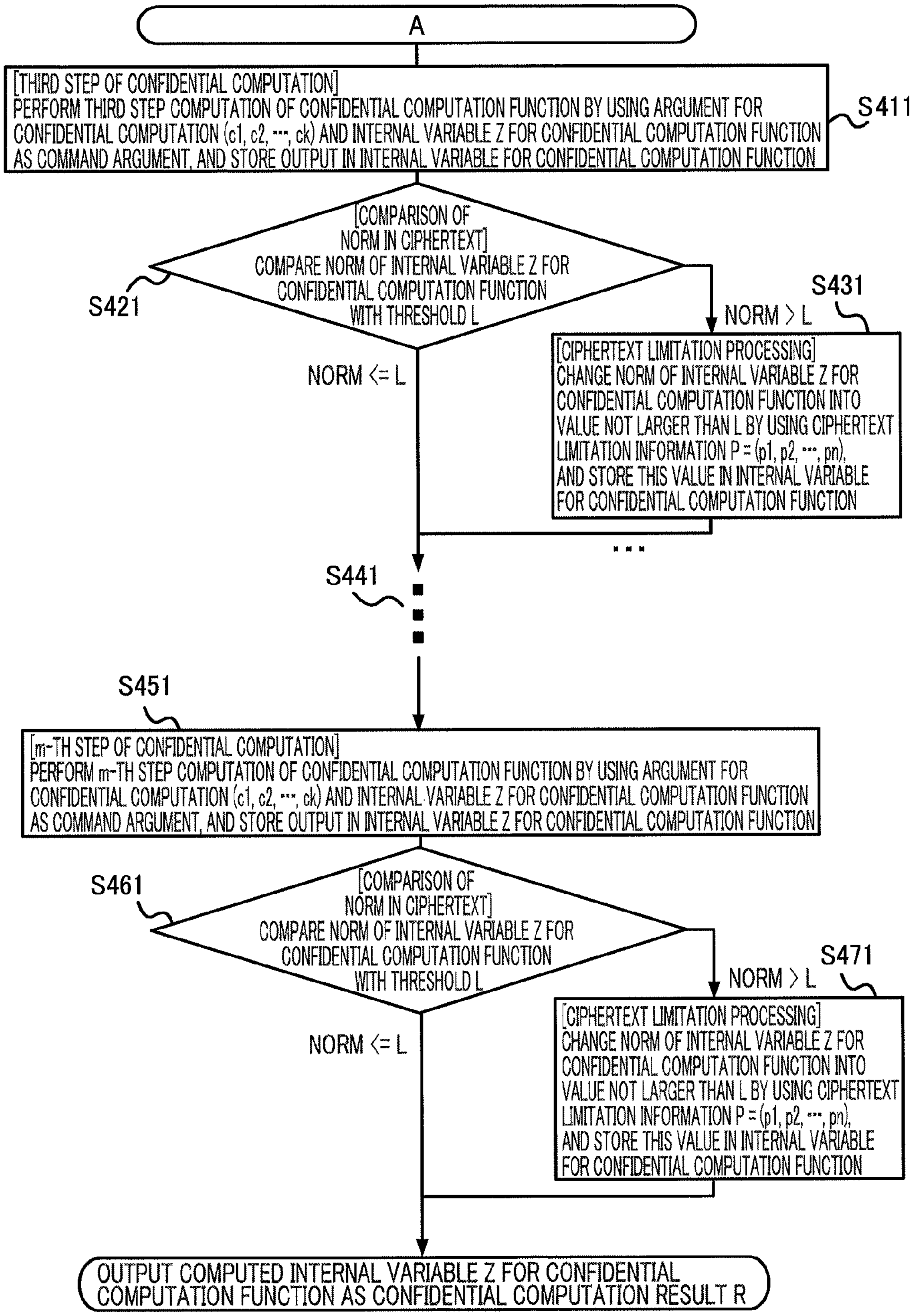

A
[THIRD STEP OF CONFIDENTIAL COMPUTATION] PERFORM THIRD STEP COMPUTATION OF CONFIDENTIAL COMPUTATION FUNCTION BY USING ARGUMENT FOR CONFIDENTIAL COMPUTATION (c1, c2, ···, ck) AND INTERNAL VARIABLE Z FOR CONFIDENTIAL COMPUTATION FUNCTION AS COMMAND ARGUMENT, AND STORE OUTPUT IN INTERNAL VARIABLE FOR CONFIDENTIAL COMPUTATION FUNCTION
S411
[COMPARISON OF NORM IN CIPHERTEXT] COMPARE NORM OF INTERNAL VARIABLE Z FOR CONFIDENTIAL COMPUTATION FUNCTION WITH THRESHOLD L
S421
NORM > L
S431
[CIPHERTEXT LIMITATION PROCESSING] CHANGE NORM OF INTERNAL VARIABLE Z FOR CONFIDENTIAL COMPUTATION FUNCTION INTO VALUE NOT LARGER THAN L BY USING CIPHERTEXT LIMITATION INFORMATION P = (p1, p2, ···, pn), AND STORE THIS VALUE IN INTERNAL VARIABLE FOR CONFIDENTIAL COMPUTATION FUNCTION
NORM <= L
S441
S451
[m-TH STEP OF CONFIDENTIAL COMPUTATION] PERFORM m-TH STEP COMPUTATION OF CONFIDENTIAL COMPUTATION FUNCTION BY USING ARGUMENT FOR CONFIDENTIAL COMPUTATION (c1, c2, ···, ck) AND INTERNAL VARIABLE Z FOR CONFIDENTIAL COMPUTATION FUNCTION AS COMMAND ARGUMENT, AND STORE OUTPUT IN INTERNAL VARIABLE Z FOR CONFIDENTIAL COMPUTATION FUNCTION
S461
[COMPARISON OF NORM IN CIPHERTEXT] COMPARE NORM OF INTERNAL VARIABLE Z FOR CONFIDENTIAL COMPUTATION FUNCTION WITH THRESHOLD L
NORM > L
S471
[CIPHERTEXT LIMITATION PROCESSING] CHANGE NORM OF INTERNAL VARIABLE Z FOR CONFIDENTIAL COMPUTATION FUNCTION INTO VALUE NOT LARGER THAN L BY USING CIPHERTEXT LIMITATION INFORMATION P = (p1, p2, ···, pn), AND STORE THIS VALUE IN INTERNAL VARIABLE FOR CONFIDENTIAL COMPUTATION FUNCTION
NORM <= L
OUTPUT COMPUTED INTERNAL VARIABLE Z FOR CONFIDENTIAL COMPUTATION FUNCTION AS CONFIDENTIAL COMPUTATION RESULT R

FIG. 9

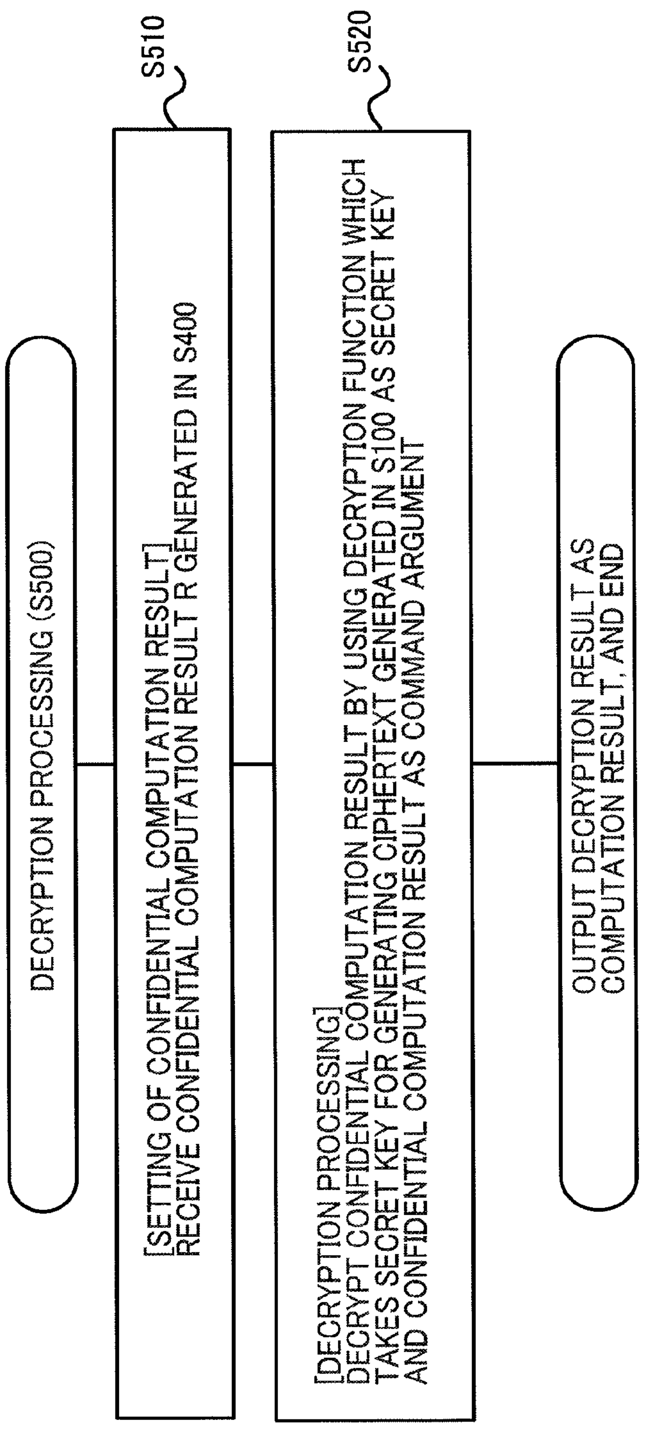

DECRYPTION PROCESSING (S500)
S510
[SETTING OF CONFIDENTIAL COMPUTATION RESULT]
RECEIVE CONFIDENTIAL COMPUTATION RESULT R GENERATED IN S400
S520
[DECRYPTION PROCESSING]
DECRYPT CONFIDENTIAL COMPUTATION RESULT BY USING DECRYPTION FUNCTION WHICH TAKES SECRET KEY FOR GENERATING CIPHERTEXT GENERATED IN S100 AS SECRET KEY AND CONFIDENTIAL COMPUTATION RESULT AS COMMAND ARGUMENT
OUTPUT DECRYPTION RESULT AS COMPUTATION RESULT, AND END

FIG. 10

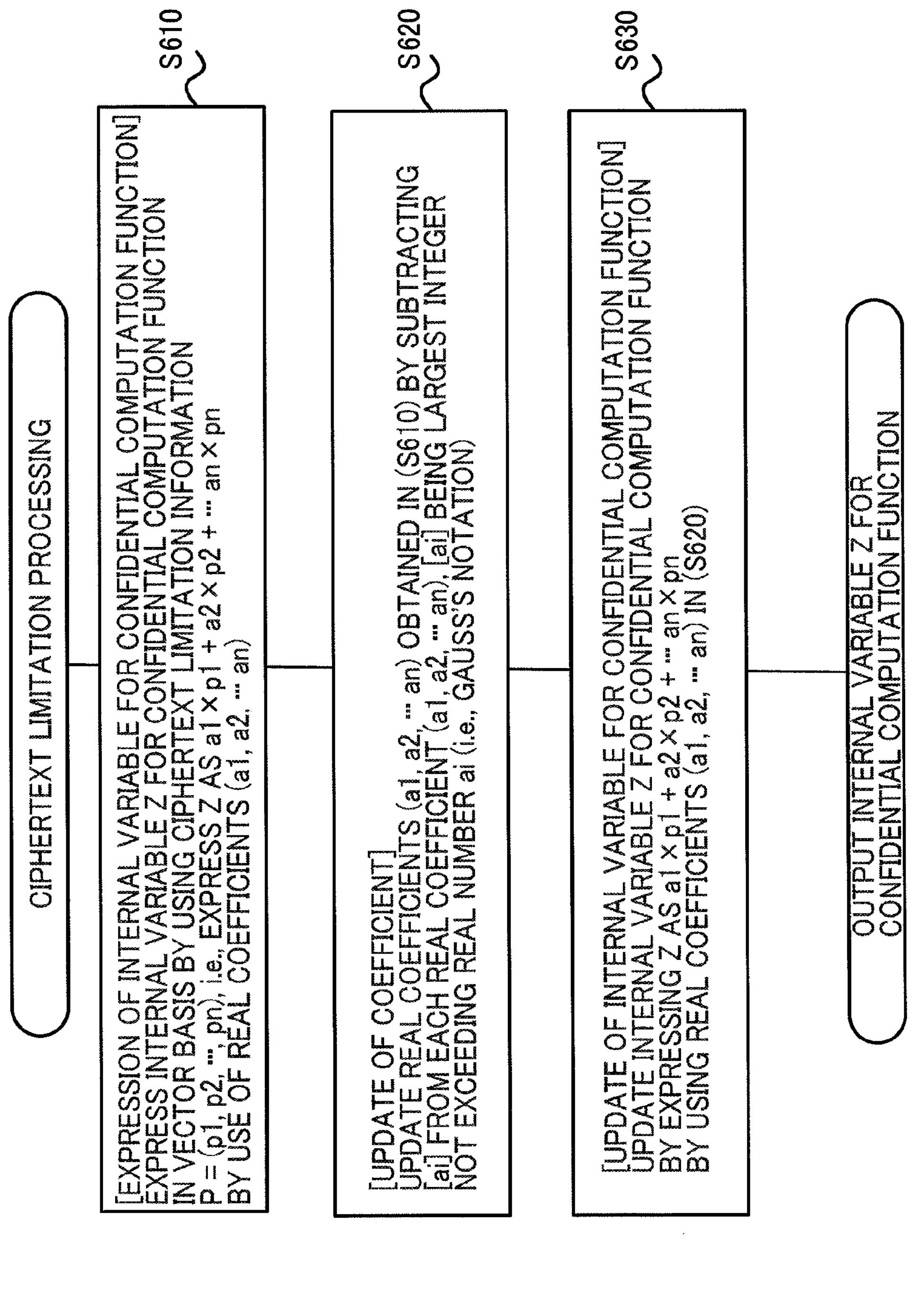

CIPHERTEXT LIMITATION PROCESSING
S610
[EXPRESSION OF INTERNAL VARIABLE FOR CONFIDENTIAL COMPUTATION FUNCTION]
EXPRESS INTERNAL VARIABLE Z FOR CONFIDENTIAL COMPUTATION FUNCTION IN VECTOR BASIS BY USING CIPHERTEXT LIMITATION INFORMATION P = (p1, p2, ⋯, pn), i.e., EXPRESS Z AS a1 × p1 + a2 × p2 + ⋯ an × pn BY USE OF REAL COEFFICIENTS (a1, a2, ⋯ an)
S620
[UPDATE OF COEFFICIENT]
UPDATE REAL COEFFICIENTS (a1, a2, ⋯ an) OBTAINED IN (S610) BY SUBTRACTING [ai] FROM EACH REAL COEFFICIENT (a1, a2, ⋯ an), [ai] BEING LARGEST INTEGER NOT EXCEEDING REAL NUMBER ai (i.e., GAUSS'S NOTATION)
S630
[UPDATE OF INTERNAL VARIABLE FOR CONFIDENTIAL COMPUTATION FUNCTION]
UPDATE INTERNAL VARIABLE Z FOR CONFIDENTIAL COMPUTATION FUNCTION BY EXPRESSING Z AS a1 × p1 + a2 × p2 + ⋯ an × pn BY USING REAL COEFFICIENTS (a1, a2, ⋯ an) IN (S620)
OUTPUT INTERNAL VARIABLE Z FOR CONFIDENTIAL COMPUTATION FUNCTION

FIG. 11

CONFIDENTIAL COMPUTATION SYSTEM, CONFIDENTIAL COMPUTATION METHOD, AND CONFIDENTIAL COMPUTATION PROGRAM

TECHNICAL FIELD

The present invention relates to a confidential computation system, a confidential computation method, and a confidential computation program, and more specifically to a technique for enabling efficient computations to be executed on outsourced data in a confidential form in a computer of a party to which the data is outsourced, while maintaining favorable security.

BACKGROUND ART

In recent years, an operational management form of an information system called cloud computing has come under the spotlight. In the cloud computing, for the purposes of efficient development of the information system, cost reduction in operational management thereof, and the like, users outsource an information system to an outside contractor instead of owning computation resources themselves. The cloud computing enables efficiency improvement and cost reduction, but on the other hand, since there are two different parties, an administrative service provider offering an information system implementing the cloud computing and a user of the information system, the user tends to feel insecure about outsourcing confidential information to the administrative service provider which is an outside contractor. For this reason, confidentiality of outsourced data needs to be ensured in advance by using an encryption technology in order to prevent misappropriation of the outsourced data.

However, in a simple encryption method, basic computations on encrypted data such as addition and multiplication, or statistical processing, computation of function values, or the like combining those basic computations can be executed only by a party capable of decrypting the data. Thus, the outside administrator of the information system, which is a party to which data is outsourced, cannot perform the various kinds of computation processing on the encrypted data. To overcome such a situation, various measures such as assigning a dedicated staff to the outsourcing contractor need to be taken, but such measures work against the cost reduction purpose, which is the original reason of employing the cloud computing.

As one of techniques for overcoming such a situation, there has been proposed an encryption method allowing a client to perform computation of arbitrary function values on data in a confidential form while outsourcing the data to a server. For example, there has been proposed an encryption method (see PLT 1) allowing Boolean addition and Boolean multiplication to be performed on bit data in a confidential form by utilizing the fact that computation of arbitrary functions executable on a computer can be represented by a combination of Boolean addition and Boolean multiplication.

CITATION LIST

Patent Literature

[PTL 1] US Patent Application Publication No. 2011/0110525

SUMMARY OF INVENTION

Technical Problem

The above-described conventional technique and the like perform encryption by adding an error vector to plaintext bit data. However, every time Boolean computation is performed on the encrypted data, the error vector inside the encrypted data increases in size. Once the size of the error vector exceeds a specific threshold, it is highly likely that correct function values cannot be derived by a decryption algorithm.

To overcome this problem, the conventional technique proposes a method in which, in order to reduce the error vector in the encrypted data, encrypted data and an encrypted secret key for decryption are inputted to an encrypted decryption function circuit, and the data is re-encrypted into encrypted data having a smaller error vector with no change made on the plaintext. By re-encrypting the data into ciphertext with a smaller error vector, the Boolean computation can be performed again until the error vector reaches a threshold. However, there is a requirement to perform this method, which is that the amount of increase in the error vector caused by the computation of the decryption function circuit needs to be equal to or smaller than the threshold. The increase in the error vector can be made no larger than the threshold by setting a sufficiently small vector as the error vector added in the first encryption of plaintext bit data. However, a small error vector allows a lattice reduction attack using a public key, and is therefore not appropriate from a security perspective. Thus, the conventional technique proposes a technique for executing re-encryption, while using a method called squashing to suppress the increase in the error vector caused by the computation of the decryption function circuit. However, this squashing poses problems of drastically increasing the data length of encrypted data as well as the amount of calculation needed for re-encryption, and is therefore not a realistic measure.

Thus, in view of the above circumstances, the present invention has an objective of enabling efficient computations to be executed on outsourced data in a confidential form in a computer of a party to which the data is outsourced, while maintaining favorable security.

Solution to Problem

A confidential computation system which is a computer system comprising: a client configured to execute data encryption by a homomorphic encryption method using a secret key and send data obtained by the encryption to a server; and the server configured to execute homomorphic computation processing on the encrypted data received from the client and return a result of the computation to the client. The confidential computation system is characterized in that: the client executes processing for executing the data encryption by adding an error vector to plaintext, the error vector being not larger than a predetermined criterion, and processing for sending limitation information to the server, the limitation information being formed from a sublattice basis of a lattice generated by the secret key; and the server executes processing for receiving the limitation information from the client and storing the limitation information in a storage device, and processing, performed in carrying out the homomorphic computation processing on the encrypted data received from the client, for reducing a bit length of ciphertext which is being subjected to the homomorphic computation processing or is a result of the homomorphic computation processing, to a value not larger than a predetermined threshold by translating a vector of the ciphertext to an inside of a region formed by the sublattice basis corresponding to the stored limitation information when the bit length of the ciphertext is equal to or larger than the predetermined value.

Advantageous Effects of Invention

According to the present invention, efficient computations can be executed on outsourced data in a confidential form in a computer of a party to which the data is outsourced, while maintaining favorable security.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** is a diagram showing an example configuration of a confidential computation system of the present embodiment.

FIG. **2** is a diagram showing an example configuration of a client terminal of the present embodiment.

FIG. **3** is a diagram showing an example configuration of a confidential computation server of the present embodiment.

FIG. **4** is a flowchart showing a processing procedure example 1 of a confidential computation method of the present embodiment.

FIG. **5** is a flowchart showing a processing procedure example 2 of the confidential computation method of the present embodiment.

FIG. **6** is a flowchart showing a processing procedure example 3 of the confidential computation method of the present embodiment.

FIG. **7** is a flowchart showing a processing procedure example 4 of the confidential computation method of the present embodiment.

FIG. **8** is a flowchart showing a processing procedure example 5 of the confidential computation method of the present embodiment.

FIG. **9** is a flowchart showing a processing procedure example 6 of the confidential computation method of the present embodiment.

FIG. **10** is a flowchart showing a processing procedure example 7 of the confidential computation method of the present embodiment.

FIG. **11** is a flowchart showing a processing procedure example 8 of the confidential computation method of the present embodiment.

DESCRIPTION OF EMBODIMENTS

System Configuration

An embodiment of the present invention is described in detail below using the drawings. FIG. **1** is a diagram showing an example configuration of a confidential computation system **10** of the present embodiment. The confidential computation system **10** (hereinafter called the system **10**) shown in FIG. **1** is a computer system including: a client configured to encrypt data with a secret key by a homomorphic encryption method and send the encrypted data to a server; and the server configured to execute homomorphic computation processing on the encrypted data received from the client and send the computation result to the client. The computer system enables efficient computations to be executed on outsourced data in a confidential form in a computer of a party to which the data is outsourced, while maintaining favorable security.

As shown in FIG. **1**, the system **10** of the present embodiment includes a client terminal **100** corresponding to the client of the present invention and a confidential computation server **200** corresponding to the server of the present invention, and the client terminal **100** and the confidential computation server **200** are configured to be able to exchange data with each other via a network **300**.

The client terminal **100** and the confidential computation server **200** constituting the system **10** have the following hardware configurations. FIG. **2** shows an example configuration of the client terminal **100** of the present embodiment. As shown in FIG. **2**, the client terminal **100** has a CPU **101**, an auxiliary storage device **102** formed by an appropriate non-volatile storage device such as a hard disk drive, a memory **103** formed by a volatile storage device such as a RAM, a tamper-resistant storage device **105**, a display device **106**, such as a display configured to display processed data, an I/O interface **107** such as a keyboard and a mouse, and a communication device **108** connected to the network **300** to perform processing for communication with the confidential computation server **200**. These devices are connected to one another with an internal signal line **104**. The CPU **101** is a computing device configured to execute programs stored in the auxiliary storage device **102** by, for example, reading them onto the memory **103** to perform overall control of the client terminal **100**. The CPU **101** also performs processing for various judgments, computations, and controls. The auxiliary storage device **102** stores therein in advance not only the programs but also plaintext data to be encrypted and a secret key used for encryption.

FIG. **3** is a diagram showing an example configuration of the confidential computation server **200** of the present embodiment. The confidential computation server **200** has a CPU **201**, an auxiliary storage device **202** formed by an appropriate non-volatile storage device such as a hard disk drive, a memory **203** formed by a volatile storage device such as a RAM, a display device **206**, such as a display configured to display processed data, an I/O interface **207** such as a keyboard and a mouse, and a communication device **208** connected to the network **300** to perform processing for communication with the client terminal **100**. These devices are connected to one another with an internal signal line **204**. The CPU **201** is a computing device configured to execute programs stored in the auxiliary storage device **202** by, for example, reading them onto the memory **203** to perform overall control of the confidential computation server **200**. The CPU **201** also performs processing for various judgments, computations, and controls.

Next, a description is given of capabilities of the client terminal **100** and the confidential computation server **200** constituting the confidential computation system **10** of the present embodiment. As described above, the capabilities to be described below are implemented by the programs in the auxiliary storage devices executed by the client terminal **100** and the confidential computation server **200**.

Note that encryption performed in the present embodiment is performed by a homomorphic encryption method using a secret key.

The client terminal **100** of the system **10** has a capability of encrypting plaintext data read from the auxiliary storage device **102** by adding an error vector to the plaintext data, the error vector being not larger than a predetermined criterion. Data obtained by the encryption, i.e., encrypted data is sent from the client terminal **100** to the confidential computation server **200**. The encrypted data sent from the client terminal **100** to the confidential computation server **200** is targeted for homomorphic computation processing.

The client terminal **100** also has a capability of sending the confidential computation server **200** ciphertext limitation information (limitation information) formed from a sublattice basis of a lattice generated by the secret key read from the auxiliary storage device **102**.

The client may preferably include a capability of deriving a matrix product of a secret key matrix stored in the auxiliary storage device **102** and a predetermined non-singular matrix of integer coefficients, and sending a matrix represented by the matrix product to the confidential computation server **200** as the ciphertext limitation information.

On the other hand, the confidential computation server **200** has a capability of receiving the ciphertext limitation information from the client terminal **100** and storing the ciphertext limitation information in the auxiliary storage device **202** or the memory **203**.

The confidential computation server **200** also has a capability of receiving the encrypted data from the client terminal **100** and executing homomorphic computation processing on the encrypted data. The confidential computation server **200** also has the following capability. Specifically, in performing this computation processing, when the bit length of ciphertext which is being subjected to the computation processing or is a result of the computation processing is equal to or larger than a predetermined threshold, the confidential computation server **200** translates a vector of the ciphertext to the inside of a region formed from a sublattice basis corresponding to the stored ciphertext limitation information to reduce the bit length of the ciphertext to a value not larger than the predetermined threshold.

The confidential computation server **200** may preferably include a capability of specifying, in a linear combination of column vectors of a limitation information matrix indicated by the ciphertext limitation information received from the client terminal **100**, a vector having the largest Euclidean distance from an origin among all the vectors each multiplied by a coefficient whose absolute value is 1 or smaller, and setting a distance between the specified vector and the origin to the predetermined threshold.

Term Definitions

Here, definitions are given for terms used in the present embodiment.

(1) An ideal lattice basis B=(b1, b2, . . . , bn): This is defined similarly to those in PTL 1. Specifically, the ideal lattice basis B=(b1, b2, . . . , bn) is an n-dimensional integer coefficient vector basis satisfying ideal lattice conditions.

(2) Ciphertext limitation information: This is a lattice basis P=(p1, p2, . . . , pn) obtained from a matrix product of the ideal lattice basis B=(b1, b2, . . . , bn) which is a secret key for generating ciphertext and a randomly-generated nxn non-singular matrix U of integer coefficients.

(3) A confidential computation program: This refers to processing in the present embodiment for performing a Boolean computation step m times by using the ciphertext (encrypted data) as an input value.

(4) An internal variable for confidential computation function: This is the name of a variable in which an output value of each step in the confidential computation program is stored so as to use the output value as an input value for the next step.

(5) An argument for confidential computation: This is ciphertext or a combination of pieces of ciphertext generated by the homomorphic encryption method by the client terminal **100** and is used an input value for the confidential computation program.

(6) A norm: This refers to a Euclidean norm. Specifically, S=v1×v1+v2×v2+ . . . , +vnxvn is found for n-dimensional integral coefficient vectors (v1, v2, . . . , vn), and the square root of the value S is the norm of the n-dimensional integral coefficient vectors (v1, v2, . . . , vn).

(7) A threshold L: When a real-coefficient linear combination is a1×p1+a2×p2+ . . . anxpn where 0<ai<=1 for the lattice basis (ciphertext limitation information) P=(p1, p2, . . . , pn), L is the norm of the vector having the largest norm among all the vectors in the linear combination.

Overall Processing Flow

With reference to a drawing, a description is given below of an actual procedure of a confidential computation method of the present embodiment. Various operations in the confidential computation method to be described below are implemented by the programs executed by the client terminal **100** and the confidential computation server **200** constituting the system **10** by reading them onto the memory or the like. These programs are formed with codes for performing various operations to be described below.

FIG. **4** is a flowchart showing a processing procedure example 1 of the confidential computation method in the present embodiment, and is, more specifically, a flow showing transmission and reception of various pieces of data for confidential computation between the client terminal **100** and the confidential computation server **200**.

First, in response to a user command received for example through the I/O interface **107**, the client terminal **100** generates a secret key for generating ciphertext by executing a program for generating a secret key for generating ciphertext (S**100**). Processing for this generation of a secret key for generating ciphertext will be described in detail later.

Next, in response to a user command or to the execution of Step S**100**, the client terminal **100** generates ciphertext limitation information by executing a program for generating ciphertext limitation information (S**200**). The client terminal **100** then sends the ciphertext limitation information (D**100**) thus generated to the confidential computation server **200** on the network **300** by use of the communication device **108**. Processing for this generation of ciphertext limitation information will be described in detail later.

Next, in response to a user command or to the execution of Step S**200**, the client terminal **100** generates ciphertext to be inputted to a confidential computation program by executing a program for generating an argument for confidential computation (S**300**), and sends the ciphertext, as an argument for confidential computation (D**200**), to the confidential computation server **200** by use of the communication device **108**. Processing for this generation of an argument for confidential computation will be described in detail later.

Meanwhile, the confidential computation server **200** receives the ciphertext limitation information (D**100**) and the argument for confidential computation (D**200**) from the client terminal **100**, and by using these as input values, executes confidential computation processing by executing the confidential computation program (S**400**). The confidential computation server **200** then sends an output value of the confidential computation program, namely a confidential computation result (D**300**), to the client terminal **100** on the network **300** by use of the communication device **203**. Processing for this confidential computation will be described in detail later.

Meanwhile, the client terminal **100** receives the confidential computation result (D**300**) from the confidential computation server **200** and performs decryption processing by executing a decryption processing program using the received confidential computation result (D**300**) as an input value (S**500**). The client terminal **100** obtains an output value of the decryption program as a computation result, and then terminates this processing. This decryption processing will be described in detail later.

Processing for Generating Secret Key for Generating Ciphertext

Next, the processing for generating a secret key for generating ciphertext is described based on a drawing. FIG. **5** is a flowchart showing a processing procedure example 2 of the confidential computation method of the present embodiment, and is, more specifically, a diagram showing the processing performed by the program for generating a secret key for generating ciphertext (S**100**) in the processing flow in FIG. **4**.

First, the client terminal **100** generates an n-dimensional ideal lattice basis B=(b1, b2, . . . , bn) by using a predetermined algorithm for generating an ideal lattice for a secret key (S**110**), and stores the generated ideal lattice basis in the tamper-resistant storage device **105** as a secret key for generating ciphertext. Note that the algorithm for generating an ideal lattice for a secret key, encryption functions, and decryption functions in the program for generating a secret key for generating ciphertext used in the present embodiment may be those used in the conventional technique in PTL 1 (a secret-key generation program, an encryption function program, and a decryption function program).

Processing for Generating Ciphertext Limitation Information

Next, the processing for generating ciphertext limitation information is described based on a drawing. FIG. **6** is a flowchart showing a processing procedure example 3 of the confidential computation method of the present embodiment, and is, more specifically, a diagram showing the processing performed by the program for generating ciphertext limitation information (S**200**) in the processing flow in FIG. **4**.

First, the client terminal **100** stores the n-dimensional ideal lattice basis B=(b1, b2, . . . , bn) in a storage area in, for example, the memory **103** secured for computation (S**210**), the n-dimensional ideal lattice basis B being the secret key for generating ciphertext generated by the program for generating an ideal lattice for a secret key (FIG. **5**: S**100**).

Next, the client terminal **100** generates a random nxn non-singular matrix U of integer coefficients by using a predetermined algorithm of an existing technique (S**220**), and multiplies the n-dimensional ideal lattice basis B set in the memory **103** by this random nxn non-singular matrix U of integer coefficients (S**230**). The client terminal **100** outputs a result of this matrix multiplication performed in Step S**230** as ciphertext limitation information represented as a matrix "P=(p1, p2, . . . , pn)". This ciphertext limitation information is to be sent from the client terminal **100** to the confidential computation server **200**.

Processing for Generating Argument for Confidential Computation

Next, the processing for generating an argument for confidential computation is described based on a drawing. FIG. **7** is a flowchart showing a processing procedure example 4 of the confidential computation method of the present embodiment, and is, more specifically, a diagram showing the processing performed by the program for generating an argument for confidential computation (S**300**) in the processing flow in FIG. **4**.

First, in response to a user command received through the I/O interface, the client terminal **100** reads, from the auxiliary storage device **102**, k pieces of plaintext m1, m2, . . . , mk for function argument, i.e., source data of encrypted data to be targeted for confidential computation, and stores the plaintext m1, m2, . . . , mk in a storage area in, for example, the memory **103** secured for computation (S**310**).

Then, the client terminal **100** encrypts each piece of the plaintext m1, m2, . . . , mk set in the memory **103** by using, as a secret key, the secret key B for generating ciphertext generated in the processing performed by the program for generating a secret key for generating ciphertext (S**100**) and by using a predetermined encryption function corresponding to the homomorphic encryption method (which encryption function may be an existing one), and thereby obtains k pieces of ciphertext as a matrix "c1, c2, . . . , ck" (S**320**). Then, the client terminal **100** outputs the matrix to the confidential computation server **200** as an argument for confidential computation.

Confidential Computation Processing

Next, the confidential computation processing is described based on drawings. FIG. **8** is a flowchart showing a processing procedure example 5 of the configuration computing method of the present embodiment, and FIG. **9** is a flowchart showing a processing procedure example 6 of the configuration computing method of the present embodiment. Specifically, FIGS. **8** and **9** are diagrams showing a flow of the confidential computation processing (S**400**) performed by the confidential computation server **200** in the processing flow in FIG. **4**.

First, from the client terminal **100**, the confidential computation server **200** receives the ciphertext limitation information P=(p1, p2, . . . , pn) generated by the client terminal **100** in Step S**200** (S**410**).

The confidential computation server **200** also receives the argument for confidential computation (c1, c2, . . . , ck) generated by the client terminal **100** in Step S**300** from the client terminal **100** (S**420**). A specific example conceivable as the argument for confidential computation is, for example, personal information requiring statistical processing with confidentiality thereof being maintained. In the present embodiment, for example, there are m individuals as statistical targets, and the confidential computation is performed for a total of m steps (first to m-th steps) to add up predetermined values each indicated by the personal information of each individual. Such an example is assumed here.

The confidential computation server **200** initializes an internal variable Z for confidential computation function (S**430**), computes a first step of the confidential computation function by using the argument for confidential computation (c1, c2, . . . , ck) acquired in Step S**420** as a command argument, and stores the output in the internal variable Z for confidential computation function (S**440**). The confidential computation function is a function for performing binomial computation such as addition and multiplication in the homomorphic encryption method capable of performing computation on ciphertext without plaintext or a secret key. As a matter of course, the confidential computation server **200** has a program for such a confidential computation function in the auxiliary storage device **102** or the like in advance.

Next, the confidential computation server **200** compares a norm of the internal variable Z for confidential computation function with a threshold L (S**450**), and proceeds to processing for performing a second step of the confidential computation function if the value of the norm is equal to or smaller than the threshold L (S**450**: norm=<L). If, on the other hand,

the norm exceeds the threshold L (**S450**: norm>L), the confidential computation server **200** changes the norm of the internal variable Z for confidential computation function into a value not larger than L by using the ciphertext limitation information P=(p1, p2, . . . , pn), stores the value in the internal variable Z for confidential computation function, and proceeds to processing for performing the second step of the confidential computation function (S**460**).

Note that the threshold L is obtained by the confidential computation server **200** by specifying, in a linear combination formed by column vectors of the matrix of the ciphertext limitation information, a vector having the largest Euclidean distance from the origin among all the vectors each multiplied by a coefficient whose absolute value is 1 or smaller, and setting the distance between the specified vector and the origin as the threshold L.

The processing for changing the norm of the internal variable Z for confidential computation function into a value not larger than L by using the ciphertext limitation information P=(p1, p2, . . . , pn), namely ciphertext limitation processing, will be described later with reference to FIG. **11**.

Next, the confidential computation server **200** performs computation of the second step of the confidential computation function by using the argument for confidential computation (c1, c2, . . . , ck) and the internal variable Z for confidential computation function as a command argument, and stores the output in the internal variable Z for confidential computation function (S**470**). Next, the confidential computation server **200** compares a norm of the internal variable Z for confidential computation function with the threshold L (S**480**), and proceeds to processing for performing a third step of the confidential computation function if the value of the norm is equal to or smaller than the threshold L (S**480**: norm=<L). If, on the other hand, the norm exceeds the threshold L (S**480**: norm>L), the confidential computation server **200** changes the norm of the internal variable Z for confidential computation function into a value not larger than L by using the ciphertext limitation information P=(p1, p2, . . . , pn), stores the value in the internal variable Z for confidential computation function, and proceeds to processing for performing the third step of the confidential computation function (S**490**).

Next, the confidential computation server **200** performs computation of the third step of the confidential computation function by using the argument for confidential computation (c1, c2, . . . , ck) and the internal variable Z for confidential computation function as a command argument, and stores the output in the internal variable Z for confidential computation function (S**411**).

Next, the confidential computation server **200** compares a norm of the internal variable Z for confidential computation function with the threshold L (S**421**), and proceeds to processing for performing a fourth step of the confidential computation function if the value of the norm is equal to or smaller than the threshold L (S**421**: norm=<L). If, on the other hand, the norm exceeds the threshold L (S**421**: norm>L), the confidential computation server **200** changes the norm of the internal variable Z for confidential computation function into a value not larger than L by using the ciphertext limitation information P=(p1, p2, . . . , pn), stores the value in the internal variable Z for confidential computation function, and proceeds to processing for performing the fourth step of the confidential computation function (S**431**).

Thereafter, the fourth step to an (m−1)th step of the confidential computation function are computed in the same procedure as that in the first to third steps of the confidential computation function described above (S**441**).

Subsequently, the confidential computation server **200** performs computation of an m-th step of the confidential computation function by using the argument for confidential computation (c1, c2, . . . , ck) and the internal variable Z for confidential computation function as a command argument, and stores the output in the internal variable Z for confidential computation function (S**451**).

Then, the confidential computation server **200** compares a norm of the internal variable Z for confidential computation function with the threshold L (S**461**), and if the value of the norm is the threshold L or smaller (S**461**: norm=<L), outputs the internal variable Z for confidential computation function as a confidential computation result R. If, on the other hand, the norm exceeds the threshold L (S**461**: norm>L), the confidential computation server **200** changes the norm of the internal variable Z for confidential computation function into a value not larger than L by using the ciphertext limitation information P=(p1, p2, . . . , pn), stores the value in the internal variable Z for confidential computation function, and outputs the internal variable Z for confidential computation function as a confidential computation result R (S**471**). This confidential computation result R is to be returned to the client terminal **100** from the confidential computation server **200**. In the above example, the confidential computation result R corresponds to a value obtained by adding up predetermined values indicated by the personal information of the m individuals.

Decryption Processing

Next, the decryption processing is described based on a drawing. FIG. **10** is a flowchart showing a processing procedure example 7 of the confidential computation method in the present embodiment, and is, more specifically, a flow showing the processing performed by the decryption processing program (S**500**) in the processing flow in FIG. **4**.

First, the client terminal **100** receives the confidential computation result R (D**200**) from the confidential computation server **200** (S**510**). Then, the client terminal **100** decrypts the confidential computation result R by using, as a secret key, the secret key B for generating ciphertext generated in the above-described processing by the program for generating a secret key for generating ciphertext (FIGS. **4** and **5**: S**100**) and using a predetermined decryption function (S**520**). The client terminal **100** outputs a value obtained by this decryption to the display device **105** as a computation result. In the above example, the computation result outputted to the display device **105** is a sum of the personal information on the m statistical-target individuals.

Ciphertext Limitation Processing

Next, the ciphertext limitation processing is described based on a drawing. FIG. **11** is a flowchart showing a processing procedure example 8 of the confidential computation method of the present embodiment, and is, more specifically, a diagram showing the ciphertext limitation processing performed in the confidential computation processing flow (S**400**) in FIGS. **8** and **9**.

First, the confidential computation server **200** expresses the internal variable Z for confidential computation function as a vector basis by using the ciphertext limitation information P=(p1, p2, . . . , pn). Specifically, the confidential computation server **200** expresses the internal variable Z for confidential computation function as Z=a1×p1+a2×p2+ . . . an×pn by use of real coefficients (a1, a2, . . . , an) (S**610**). Next, the confidential computation server **200** subtracts [ai] from each ai (i=1 to n) obtained in Step S**610**, the [ai] being the largest integer not exceeding the real number ai, and thereby updates each coefficient ai to a value "ai−[ai]." (S**620**) For example, if a1 is "3.5," "3" which is the largest integer not exceeding the real number "3.5" is subtracted from "3.5" to update the coefficient al to a value "0.5."

Next, the confidential computation server **200** updates the internal variable Z for confidential computation function into Z=a1×p1+a2×p2+ . . . an×pn by using each coefficient ai obtained in Step S**620** (S**630**), and outputs this internal variable Z for confidential computation function. Such processing is, in other words, processing for reducing the bit length of ciphertext to a predetermined value or less by translating a vector of ciphertext yet to be limited ("ai" exceeds 1) to the inside of a region formed from a sublattice basis corresponding to the ciphertext limitation information (to make "ai" 1 or smaller).

Note that the random nxn non-singular matrix U of integer coefficients generated in the above embodiment in generating the ciphertext limitation information may be a random nxn non-singular matrix U of integer coefficients in which a determinant value satisfies a certain condition. In addition, although a Euclidean norm computation approach is used as a method for computing the norm of a vector, other conventional norm computation approaches may be used instead. Moreover, although the internal variable for confidential computation is a single variable Z in the above embodiment, the internal variable for confidential computation may be a combination of multiple variables (Z1, Z2, . . . , Zk).

The best mode for carrying out the present invention and the like are specifically described above, but the present invention is not limited thereto and may be variously changed without departing from the gist thereof.

The present embodiment employs the method: using a sufficiently small error vector added in encrypting plaintext bit data by the client terminal **100** in order to suppress the "increase in an error vector caused upon re-encryption" which is a problem in the prior art; and keeping confidential a public key, which is conventionally opened, in order to prevent a lattice reduction attack, the risk of which is increased by the small error vector. The problem of an increase in the norm in ciphertext is overcome as follows. Specifically, the confidential computation server **200** acquires ciphertext limitation information (information for limiting the bit length of ciphertext to a certain constant or smaller) generated in the client terminal **100**, the information being unlike a conventional public key. The ciphertext limitation information is formed from a sublattice basis of a lattice generated by a secret key, and the norm increase is prevented, whenever it occurs, by translating the ciphertext vector to a fundamental region generated by the sublattice basis. The norm can be reduced by translating the vector without changing plaintext information of the ciphertext vector since the vector added is a vector of a sublattice.

Further, since the ciphertext limitation information is a sublattice basis of a lattice which is a secret key, an encryption algorithm using a conventional public key cannot be used anyway. Thus, even if a lattice reduction attack is made on the ciphertext limitation information in the confidential computation system of the present embodiment, the probability of the ciphertext being decoded and plaintext being outputted is extremely low. Actually, the probability of the ciphertext being decoded is about D/D' where D is an absolute value of a determinant of a matrix formed from a lattice basis of a secret key and D' is an absolute value of a determinant of a matrix formed from a lattice basis of the ciphertext limitation information. Thus, by making D' sufficiently large, the probability can be made a small value which does not pose a problem in practice.

Thus, the present embodiment allows reduction in an error vector added to plaintext bit data compared to a conventional one to suppress an increase in the error vector caused by Boolean computation on the encrypted data, and at the same time, allows avoidance of a lattice reduction attack which is conventionally concerned when the error vector is small. Thus, there is no need for employing an approach that requires an extremely large amount of computation and time, like squashing. Hence, efficient computation can be executed on outsourced data in a confidential form in a computer of a party to which the data is outsourced, while maintaining favorable security.

The description herein makes at least the following points clear. Specifically, in the confidential computation system, the client may obtain a matrix product of a secret key matrix stored in the storage device and a predetermined non-singular matrix of integer coefficients and send the server a matrix which is a result of the matrix product, as the limitation information.

In addition, in the confidential computation system, the server may specify, in a linear combination formed by column vectors of the limitation information matrix which is indicated by the limitation information received from the client, a vector having the largest Euclidean distance from an origin among all vectors each multiplied by a coefficient whose absolute value is 1 or smaller, and set a distance between the specified vector and the origin as the predetermined threshold.

REFERENCE SIGNS LIST

10	confidential computation system
100	client terminal (client)
101	CPU
102	auxiliary storage device (storage device)
103	memory
104	internal signal line
105	tamper-resistant storage device
106	display device
107	I/O interface
108	communication device
200	confidential computation server (server)
201	CPU
202	auxiliary storage device (storage device)
203	memory
204	internal signal line
206	display device
207	I/O interface
208	communication device
300	network

The invention claimed is:

1. A confidential computation system which is a computer system comprising:

a client configured to execute data encryption by a homomorphic encryption method using a secret key and send the encrypted data to a server; and

the server configured to execute homomorphic computation processing on the encrypted data received from the client and return a result of the computation to the client, the confidential computation system characterized in that

the client executes

processing for executing the data encryption by adding an error vector to plaintext, the error vector being not larger than a predetermined criterion, and

processing for sending limitation information to the server, the limitation information being formed from a sublattice basis of a lattice generated by the secret key, and

the server executes

processing for receiving the limitation information from the client and storing the limitation information in a storage device, and

in the homomorphic computation processing on the encrypted data received from the client, processing for, when a bit length of ciphertext which is under the homomorphic computation processing or is a result of the homomorphic computation processing is equal to or larger than a predetermined value, reducing the bit length of the ciphertext to a value not larger than a predetermined threshold by translating a vector of the ciphertext to an inside of a region formed from the sublattice basis corresponding to the stored limitation information.

2. The confidential computation system according to claim **1**, characterized in that

the client performs matrix multiplication of a secret key matrix stored in the storage device and a predetermined non-singular matrix of integer coefficients and sends the server a matrix which is a result of the matrix multiplication, as the limitation information.

3. The confidential computation system according to claim **1**, characterized in that

the server specifies, in a linear combination formed by column vectors of a limitation information matrix which is indicated by the limitation information received from the client, a vector having the largest Euclidean distance from an origin among all vectors each multiplied by a coefficient whose absolute value is 1 or smaller, and sets a distance between the specified vector and the origin as the predetermined threshold.

4. A confidential computation method performed in a computer system including a client configured to execute data encryption by a homomorphic encryption method using a secret key and send the encrypted data to a server, and the server configured to execute homomorphic computation processing on the encrypted data received from the client and return a result of the computation to the client, the confidential computation method characterized by comprising:

causing the client to execute

processing for executing the data encryption by adding an error vector to plaintext, the error vector being not larger than a predetermined criterion, and

processing for sending limitation information to the server, the limitation information being formed from a sublattice basis of a lattice generated by the secret key, and

causing the server to execute

processing for receiving the limitation information from the client and storing the limitation information in a storage device, and

in the homomorphic computation processing on the encrypted data received from the client, processing for, when a bit length of ciphertext which is under the homomorphic computation processing or is a result of the homomorphic computation processing is equal to or larger than a predetermined value, reducing the bit length of the ciphertext to a value not larger than a predetermined threshold by translating a vector of the ciphertext to an inside of a region formed from the sublattice basis corresponding to the stored limitation information.

5. A non-transitory computer-readable storage medium with an executable program stored thereon, wherein the program instructs a microprocessor to execute data encryption by a homomorphic encryption method using a secret key and send data obtained by the encryption to a server, and the server configured to execute homomorphic computation processing on the encrypted data received from the client and return a result of the computation to the client, the confidential computation program causing the server to execute

processing for receiving, from the client, limitation information formed from a sublattice basis of a lattice generated by the secret key, and storing the limitation information in a storage device,

and

in the homomorphic computation processing on the encrypted data received from the client, processing for, when a bit length of ciphertext which is under the homomorphic computation processing or is a result of the homomorphic computation processing is equal to or larger than a predetermined value, reducing the bit length of the ciphertext to a value not larger than a predetermined threshold by translating a vector of the ciphertext to an inside of a region formed from the sublattice basis corresponding to the stored limitation information.

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